

SCOTT POLAR RESEARCH INSTITUTE

Sea Ice Group

The Breaking of Sea Ice by Ocean Waves

A preliminary report on fieldwork carried  
out in South Labrador during January to  
April 1975.

By

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## Summary

A joint field project was carried out in the Winter of 1975 between The Scott Polar Research Institute and Memorial University of Newfoundland on the sea ice at FORTEAU Bay, South Labrador. The project was concerned with the effect of ocean swell on sea ice and with the hypothesis that sea ice is primarily broken up by the action of ocean waves.

A geophysical wire strainmeter was used to detect and measure strains due to gravity waves on the ice surface. When a number of strainmeters were positioned in various arrays the complete wave characteristics could be defined.

The results of the experiments are discussed and the principal conclusions are; that the break-up of all observed fast ice in FORTEAU Bay was caused by wave action and that the likelihood of break-up could be predicted with the strainmeter. The most significant swell was produced by distant storms in the Atlantic; locally produced waves in the Gulf of St. Lawrence were of little significance. Waves were detected at all times and at all points on the fast ice throughout the experiment. Data are presented on meteorological conditions and ice growth and decay.

Finally, some attention is given to the future possibilities arising from this work.





# The Breaking of Sea Ice by Ocean Waves

## Introduction

For some years the Scott Polar Research Institute has been conducting research into the interaction of ocean swell and sea ice. The current phase of this work has been directed towards the detection and measurement of wave parameters, at or close to, the open ocean edge of a sheet of fast ice. This has necessitated the design of new sea ice instrumentation and the perfection of fieldworking techniques at this potentially dangerous area.

During the early planning of this experiment it was felt that a project of this type would greatly benefit by the joint co-operation with a Canadian organisation with similar interests to ourselves. We were fortunate and grateful that the Ocean Engineering Group of Memorial University of Newfoundland agreed to work with us on this venture, allowing interchange of ideas and personnel in addition to practical, logistic support.

The experiment required a site having smooth fast ice, thick enough to work on, with a clean edge adjacent to open water, big enough to provide a good wind fetch for swell generation. At that time Memorial University were engaged on an ice research programme in the Strait of Belle Isle and suggested that their research station at the Point Amour Lighthouse in South Labrador would provide a suitable site. A reconnaissance was made of this site in October 1974 by Mr Allan (SPRI), Mr Langford (MUN) and Mr Campbell (MUN). The lighthouse, which is not in use during the winter months, is situated on the north shore of the southern end of the Strait of Belle Isle, just east of the mouth of Forteau Bay. Forteau Bay develops a good ice cover and there is normally a clean ice edge across the mouth of the Bay caused by the shear effect of the strong tidal currents (3 to 4 knots) up and down the Strait. The lighthouse itself would make an excellent observation platform for monitoring sea and ice conditions in the Strait and at the mouth of the Bay, whilst simple but comfortable accommodation was available in the adjacent living quarters. A shed, belonging to the lighthouse, was situated right on the shore at L'Anse Amour, a small community some 2 km from the lighthouse complex. The shed would make an ideal laboratory to house the recording instruments. One final and important factor in deciding on this site was that the lighthouse keeper, Mr Maxwell Sheppard, who has a great deal of local knowledge of ice conditions, would be available to work for us during the winter.





Immediately after the reconnaissance the decision was taken to go ahead with the experiment in Forteau Bay. The original plans, however, had to be reduced to a minimum on account of the limited funding available. Broadly speaking, a three-man team consisting of a research worker, a technician and a part-time local employee would occupy the station continuously from the beginning of February 1975 until break-up sometime in April 1975. During the intervening months Memorial University would supervise the construction of a small laboratory in the shed and arrange for mains electricity to be laid on. They would also collect together the necessary field equipment and arrange the transport to Labrador. The Scott Polar Research Institute would design and produce the field instruments and plan the overall experiment.

### Objectives

It was undesirable to define too rigidly the objectives of an experiment such as this, since variable ice and weather conditions would require maximum flexibility in our plans. However, we intended to work in the following three areas of study:

1. To test our hypothesis that the break-up of fast ice is primarily due to stresses induced by sea waves and to conduct various experiments to expand our understanding of the flexing of sea ice by swell.
2. To continue field testing and improving a new instrument for measuring strain on the top surface of the ice and to field test a new pressure sensor to measure the pressure changes at the ice/water interface.
3. To gain practical experience of working at an ice edge so that a safe procedure may be devised for any such future experiments.

### The Instruments

The principal instrument used in these experiments is a new wire strainmeter, originally developed by the Department of Geophysics in Cambridge for measurements of earth strain. We have made minor modifications to adapt the instrument for use on ice. The strainmeter uses a length standard of Invar wire, normally two metres long, which is held in tension by a lever and weight system. Movement of the lever is detected electronically by a displacement transducer, amplified, filtered and recorded on a chart recorder. When used over ten meters the maximum resolution is  $10^{-10}$ , providing the temperature is stable. Thus, the instrument can easily resolve the very small strains caused by gravity waves at considerable distances from the sea edge of fast ice.



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Preliminary trials of the strainmeter were carried out at Thule, north west Greenland in the Spring of 1974 and although a number of difficulties were encountered, which have subsequently been corrected, strains were measured near the ice edge giving a frequency spectrum corresponding to typical sea waves (*Nature*, Vol. 255, May 1st 1975). For the Labrador experiment we decided to construct a three-channel strainmeter array which would allow various configurations of strain measurements to be made at any one time. Because of the danger of losing instruments during ice break-up it was decided to keep the recording equipment and associated electronics in the laboratory on the shore. The measuring instruments were connected to the recorder by multicore cable allowing a maximum range of 1.1 km from the recording equipment. This range would allow us to place the instruments at the ice edge where water depth was about 50m.

The pressure change at the ice/water interface due to the passage of a wave beneath the ice was another parameter we wished to measure. As it would be necessary to freeze the sensor onto the bottom surface of the ice it was likely that the instrument would be lost during break-up, hence it was desirable that the sensor be as inexpensive as possible. The only transducer available that was relatively cheap and could withstand a seawater environment was the recently developed 'Pitran' piezo-transistor. A change in the gain of the transistor is produced when a differential pressure is applied to the diaphragm. The signal is processed and transmitted to the recorder down the same multicore cable as the strainmeter. The major difficulty with this system is that the piezo-transistor is highly temperature dependent, however, when the sensor, its power supply and associated electronics are all encapsulated in an insulated probe and maintained in position at the bottom surface of the ice, where the sea temperature is very stable, this does not present any difficulty. The reference side of the diaphragm is vented to the atmosphere via a tube within the probe so that variations in atmospheric pressure are automatically cancelled.

#### Schedule of Main Events

24 October to 1 November 1974

Preliminary reconnaissance.

28 January 1975

Mr Alastair Allan (Investigator) and Mr Terry Ridings (Technician) fly from London to St. John's.

29 January to 4 February

Testing and demonstrating equipment at Memorial University. Purchasing supplies and arranging transport. Particularly difficult as town was in state of emergency due to heavy snowfall.





5 February

Flew to Labrador in chartered Single Otter aircraft. Very rough journey due to heavy load and excessive turbulence. Landed in the dark at the Forteau Upper Pond.

6 February

Employed Mr Maxwell Sheppard as part-time assistant. Freight equipment to the shore laboratory and living quarters. Began work on installations in laboratory and making living quarters habitable.

10 February

Initiated daily routine of observations of ice conditions in (a) Strait of Belle Isle area (b) the area off the mouth of Forteau Bay, from the Lighthouse. Initiated daily observation of the nature and position of the ice edge in Forteau Bay. Began routine ice thickness measurements at various sites in the Bay. Erected recording anemometer and wind direction indicator at a site on the fast ice in the Bay.

11 February

Began routine collection of twice daily (1200 and 2400 G.M.T.) synoptic weather observations from the lighthouse site.

20 February

First strainmeter installed on the ice at site A, 200m from the shore laboratory.

4 March

Laid the first 500m of multicore cable and established Site B 500m SW from the shore laboratory. Installed three strainmeters at this position.

7 March

Surveyed in a grid of marker flags at 100m intervals from the ice edge to serve as a calibration for the photogrammetry of ice break-up.

11 March

Located cause of major upset on equipment due to brine forming 'batteries' in the connectors.

20 - 23 March

Very warm weather causing great problems fixing instruments to ice. Snow and upper surface of ice rapidly melting. 10 cm of brine on top surface flooding instruments.





25 March

Successfully mounted instruments on bed of sand, thus resolving the melting problem.

25 - 26 March

Large amplitude waves measured, indicating imminent break-up. Monitored instruments throughout night. Major break-up of about 500m of heavily pressured ice during the early morning.

27 March

Initiated time lapse cine camera observations of ice edge.

28 March

Installed pressure sensor at site B.

2 April

Established site C at the ice edge and laid a further 500m of cable.

3 April - 4 April

Conducted the edge experiments and then removed all cables and equipment from ice.

8 April

Took opportunity of free ride in Beaver aircraft to survey ice edges from Forteau to Red Bay using false colour infra red photography. Established Site D 100m west from the laboratory.

9 April

Began experiment to relate strain, vertical amplitude and pressure.

17 April

Complete ice break-up imminent. Removed all equipment and packed up ready to leave.

18 April

Major ice break-up around the laboratory and in Forteau Bay. Flew back to St. John's in the afternoon by scheduled flight.

28 April

Returned to U.K.

### Summary of Specific Experiments

#### 1. Site A. 200m West of Laboratory





A single strainmeter was emplaced perpendicular to the ice edge to examine the long term nature of wave-induced strains, particularly long term drift in relationship to temperature variation.

## 2. Site B. 500m S.W. of Laboratory

Three strainmeters positioned in an array,  $45^{\circ}$  apart on the ice surface, to resolve the principal axes of the strain tensors in the two dimensional system.

## 3. Site B

Three strainmeters set perpendicular to the edge and parallel to each other, but set at 1m, 2m and 2.5m length standards.

## 4. Site B

Two pressure sensors with differing ranges and a temperature sensor emplaced at the ice/water interface to examine the nature of pressure changes at the lower ice surface.

## 5. Site B

Experiment to mount strainmeter on (a) snow surface, and (b) sand bed, to resolve the problem of fixing strainmeters to the ice in temperature conditions above the freezing point.

## 6. Site B

Experiment to measure the vertical amplitude of waves by theodolite and staff and relate it to surface strain.

## 7. Site C. 1km from laboratory and at ice edge

Experiment to measure phase change in waves at various distances from the ice edge.

## 8. Site D. 100m west of Laboratory

Two strainmeters set at right angles to each other and related to vertical amplitude observations by theodolite and staff.

The data from the above experiments are recorded on nearly 2 km of three-tracked paper chart. The analysis of this will clearly take some time and even then, only a proportion will be analysed. Most of the charts were superficially scanned and checked on the site so we were able to reach some qualitative rather than quantitative conclusions, which will be discussed later.

### Additional Observations

1. Ice thickness observations on a routine basis. Data presented in appendix (i).
2. Synoptic weather observations at the lighthouse site at 1200 and 2400





G.M.T. The data are presented in appendix (ii).

3. Wind speed and direction were recorded at a height of 3 m at a site, initially on the ice, later on the shore during the melting phase. The recorder was unreliable and there are a number of gaps in the record. The data are presented in appendix (iii).
4. Daily observation of the position and nature of the fast ice edge. This was surveyed by compass and tape technique and recorded by daily photography. Edge positions are shown on the accompanying map.
5. Daily observation of pack ice conditions in (a) The Strait of Belle Isle area, and (b) the area at the mouth of Forteau Bay. This was recorded by photography and visual estimates were made of floe size, thickness, concentration, polynyas etc.
6. Photogrammetry of the ice edge during break-up to measure size of breaking floes in relation to incoming wave characteristics. An 8mm time-lapse cine camera mounted on a nearby cliff gave a good record of the break-up process but the resolution was not good enough for measurement. Better measurements were obtained from 35 mm still photography.
7. Experiments were made to attempt to map the very fine cracks at the ice edge caused by wave action. The cracks could be mapped from the ice surface using conventional survey techniques but this is laborious and dangerous. We attempted photogrammetrical mapping from the ice surface and from the air using false colour infra red and monochrome infra red film as well as ordinary colour and monochrome film. There was no advantage in using anything other than ordinary monochrome film. If the cracks are to be mapped from the air the aircraft should fly low (not more than 100m) in order to resolve the fine crack lines.

It had been intended to conduct an ice crystalsize analysis, but although we had all the equipment available we had to abandon this part of the programme due to lack of time. However, some time was given in assisting Memorial University's ongoing programme of ice floe and iceberg tracking by time-lapse camera, theodolite and radar. The local population, who are naturally very concerned about the management and understanding of sea ice problems, took a keen interest in our work and numerous groups were shown round the laboratories and working sites and a lecture was given on some of the wider aspects of the work in the local school.



### Problems

Some mention should, perhaps, be made of some of the difficulties encountered, for the project was by no means easy. The greatest problem by far was due to the unreliability of our hired Skidoo. The engine had to be stripped and reassembled four times and there was an endless list of breakdowns of other parts. It is considered essential that at least two snowmobiles are available for any future project in the area.

Domestic work; cooking, washing, etc. took up a seemingly disproportionate amount of time which could have been better spent working on the ice. Even though time consuming it did, at least, provide a change of working routine.

A particularly annoying problem was the appalling communications system between St. John's and Labrador. One urgent parcel took six weeks to be air freighted from St. John's, whilst another never arrived at all. The problem seems to lie somewhere between the despatching office, the scheduled airline across Newfoundland and the onward charter to Labrador. The ordinary mail was marginally quicker.

The weather in Labrador had a bad reputation but we never found it as severe as anticipated. Work was impossible, of course, in blizzard conditions but the subsequent heavy snow drifts only occasionally prevented transport between the lighthouse and laboratory. Installation of instruments on the ice in conditions of low, drifting snow was ill-advised since the instruments would rapidly become choked by fine particles of snow. It was also extremely uncomfortable on bare hands. From our point of view the most serious disadvantage of the Labrador weather was the occasional very warm periods, which often brought rain. This and the melting of the snow gave serious problems with flooding of instruments and melting out of the terminal anchors.

### Results

The various experiments produced 90 rolls of three tracked recorder charts, which have only yet been superficially examined. The digitisation and computer analysis will be a lengthy task, hence, the conclusions reached here are essentially qualitative rather than quantitative.

### The Instruments

The strainmeters worked very well and proved to be an ideal way of measuring the surface strain due to gravity waves. They are especially suitable for the detection and measurement of gravity waves with very small





amplitudes (less than 1 cm). When dealing with large amplitude waves, such as are likely to cause ice fracture (greater than 10cm) the incoming signal had to be attenuated by over 90% and we believe this would justify the design and construction of a cheaper, less sensitive but more robust instrument, which could be considered 'disposable', for use when large amplitude waves are encountered and when break-up is likely. The existing strainmeters still, of course, have an important role to play in future work and we have made the following observations and design suggestions:

1. The long term drift is due to pressure melting of the terminal anchors. The tension on the wire, therefore, should be reduced as much as possible. Alternatively a rigid length standard may be used. Pressure melting depends on the temperature of the ice surface and when this is below  $-20^{\circ}\text{C}$  the present arrangement would probably work satisfactorily.
2. Mounting the terminal anchors on a bed of sand will successfully overcome the problem of fixing to the ice during melting or flooding of the top surface. However, the sand takes at least 24 hours to settle after the instrument has been placed, therefore, the rapid change of instrument position is not possible. There is also the problem of frost heaving in the sand if there are extreme freeze/thaw cycles during the period of measurement. However, this was not a problem in Labrador.
3. The self zeroing servo motor operated too slowly due to loss of voltage down the cold connecting cable to the chart stepper. This can be overcome by providing a control unit and power supply at the instrument site.
4. The strainmeter lever locking mechanism was impossible to operate in cold conditions and as a result we damaged transducer cores and flexure pivots, which affect the calibration of the instrument. A more robust locking device can be designed.
5. Under certain circumstances we obtained cross interference on the channels. This is being investigated at the moment and it seems likely that it was due to the power supply circuit in the recorder. We believe this can be modified to reduce this effect.
6. All plugs and sockets used on the ice should be changed to high quality military specification types, preferably with plastic shells and covers to completely reduce contamination by brine.

The pressure sensor probes proved to be unsatisfactory. Although traces were obtained from both probes they appear to be unintelligible at present. Certainly we are not getting a record compatible with the simultaneous strain measurements. One of the piezo-transistors seemed to have inferior quality





gold plating as about 70% of the plating in contact with the seawater was lifted off after 24 hours immersion. Another possibility is that the piezo-transistors had been damaged by overpressure and this is being checked at present. We know by visual observation of the fluctuations in sea level in holes in the ice that a pressure change occurs when a gravity waves passes through the ice. A rough order of magnitude estimation would indicate that we were seeing a 5mm head of water pressure change for a wave of approximately 5cm amplitude and 12 sec period. We would strongly recommend that further work be done on the measurement of pressure but utilising a much more reliable and robust transducer, possibly one of the L.V.D.T. type. The piezo-transistor, if reliable, could still be used as a cheap 'disposable' pressure probe.

### Scientific Results

1. The instrument records show that waves are present at all times and at all points on the fast ice during the experimental period. Only occasionally (about 5% of the time) were total strains of less than about  $10^{-6}$  encountered.
2. We are assuming that most of our strainwaves are equated to gravity waves, but there is a possibility that we are also measuring waves of compressive strain or shear strain. This should be resolved by the simultaneous measurement of a different parameter, such as tilt, pressure, or acceleration.
3. The break-up of all observed fast ice in Forteau Bay was caused solely by wave action. Wind and water shear stresses appear to be insignificant in the breaking process, but are of great importance in the transport of the floes away from the ice edge.
4. We were able to resolve the primary direction of propagation of the wave trains. This was mostly from the Gulf of St Lawrence. However, the principal break-up was due to swell propagating down the Strait of Belle Isle from the Atlantic.
5. The instrument showed that swell capable of breaking the ice had a characteristic period and amplitude. We could thus predict, generally up to 12 hours in advance, when break-up was likely.
6. We should be in a position to find the relationships between strain, amplitude, period and wavelength for gravity waves in ice to compare with the theoretical relationships, and we believe we can relate these variables to the size and shape of the resultant broken pieces of fast ice.

### The Future

These series of experiments should not be considered conclusive in themselves but more as an indicator of a new and profitable field of sea



ice study. Some of the general areas requiring further work are listed below.

### 1. Instrument engineering

There is a need to improve the existing strainmeter, to design a new, cheap, low sensitivity strainmeter, to continue experimentation with pressure sensors, tiltmeters and accelerometers, and in the longer term, to consider the possibility of digital recording and telemetry of data.

### 2. Physics of Ice

We should try to understand and explain the physical mechanisms behind the flexure and fatigue stressing of sea ice by ocean waves.

### 3. Break-up prediction

There should be a reappraisal of the factors causing break-up of fast ice and the size, shape and distribution of subsequent pack ice. A geographical model should be constructed to relate the pattern of swell, possibly produced by distant storms, to break-up of fast ice.

4. Similar experimental programmes should be conducted in different geographical locations with variable conditions of swell, wind fetch, ice thickness, pack ice concentration, etc.

5. Similar work should be carried out on ice floes in the marginal ice zone in the open sea. There is particularly a need to monitor swell characteristics in the open sea and relate these to the measured strains on the ice surface.

### 6. Engineering Applications

There are numerous engineering requirements to investigate ice strains in relation to various structures. But the most interesting project following from this work is an examination of strains on ice produced by (a) conventional icebreakers, and (b) hovercraft.

### Postscript

Perhaps the most satisfying result for us is that as the experiment progressed we became more and more convinced that the ice was broken only by ocean swell and we became equally confident that our instrument could predict the actual time of break-up. In contrast it was a well-established tradition amongst the local fishermen that break-up was caused by the north east wind. These opposing views were held so strongly by the two parties that it became a point of honour to hold a friendly wager on the time of break-up, each using their own criterion. The odds were a quantity of dried codfish (much valued by the scientists) verses a quantity of Invar wire (the finest rabbit snares in the whole of Labrador). Needless to say, the outcome of the conflict was resolved in favour of the





wave men, who won the betting every time and accumulated more codfish than they could possibly eat, whilst the fishermen (who got their snares anyway) became a little less sceptical about scientific methodology.

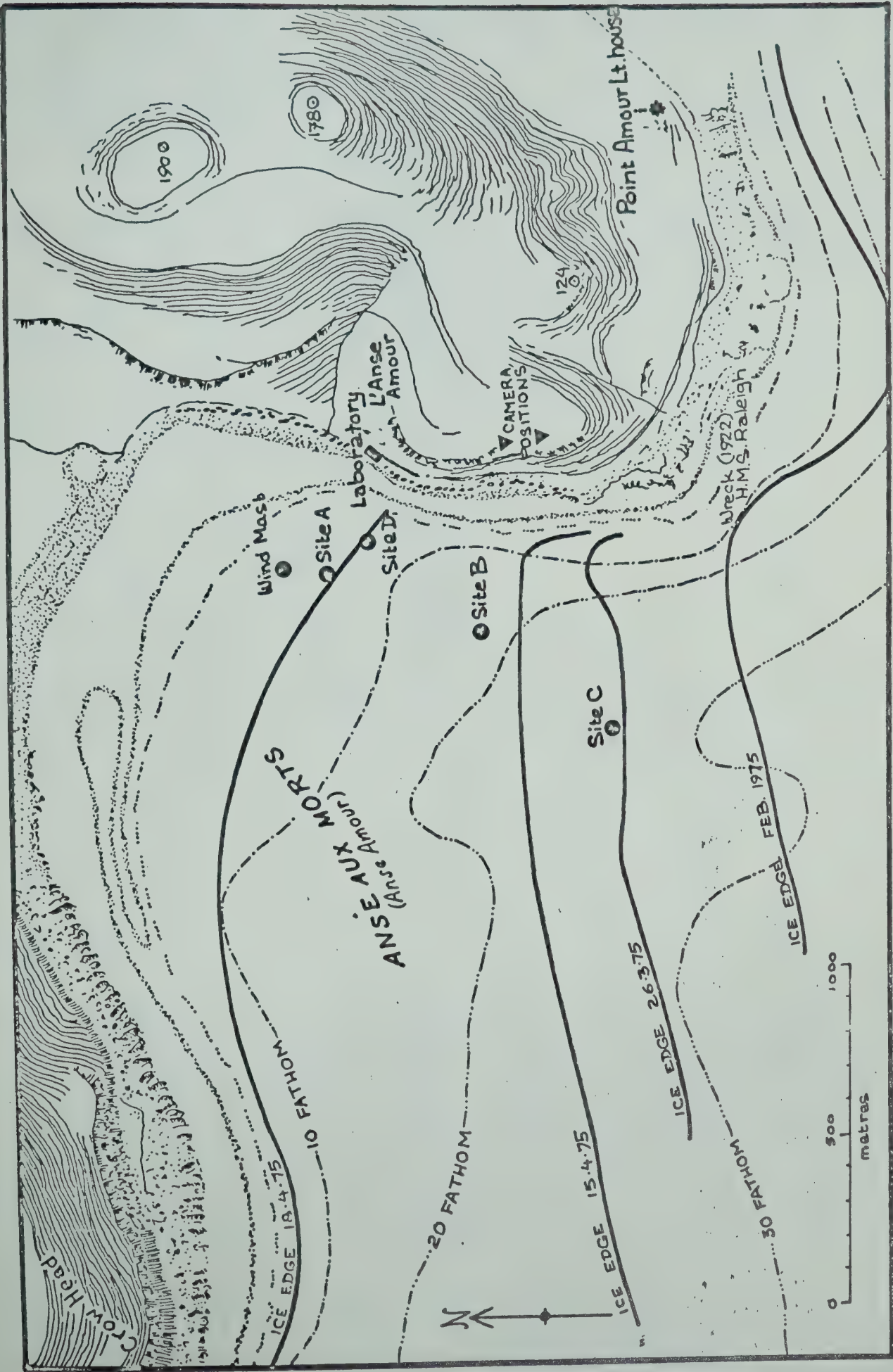
#### Acknowledgements

There were many people involved with this project and I would particularly like to thank Dr G de Q Robin for his continuous support of the work and Dr A Bruneau who invited the project to Newfoundland. My thanks too, to the members of the Ocean Engineering Group of Memorial University of Newfoundland for all their work, encouragement and hospitality. The Earth Strain Group of the Department of Geophysics and D J Goodman of the Cavendish Laboratory in Cambridge gave considerable help with the strainmeter part of the programme. My special thanks go to my two colleagues in the field, Terry Ridings and Max Sheppard, whose goodhumour made the task pleasant in often uncomfortable conditions, and to the people of South Labrador, who tolerated our intrusion into their community with such good grace. We are still trying to eat their salt codfish!

The project was jointly funded in Britain by The Royal Society and B.P. Trading Co. and in Canada by Fisheries and Marine Division of Environment Canada.





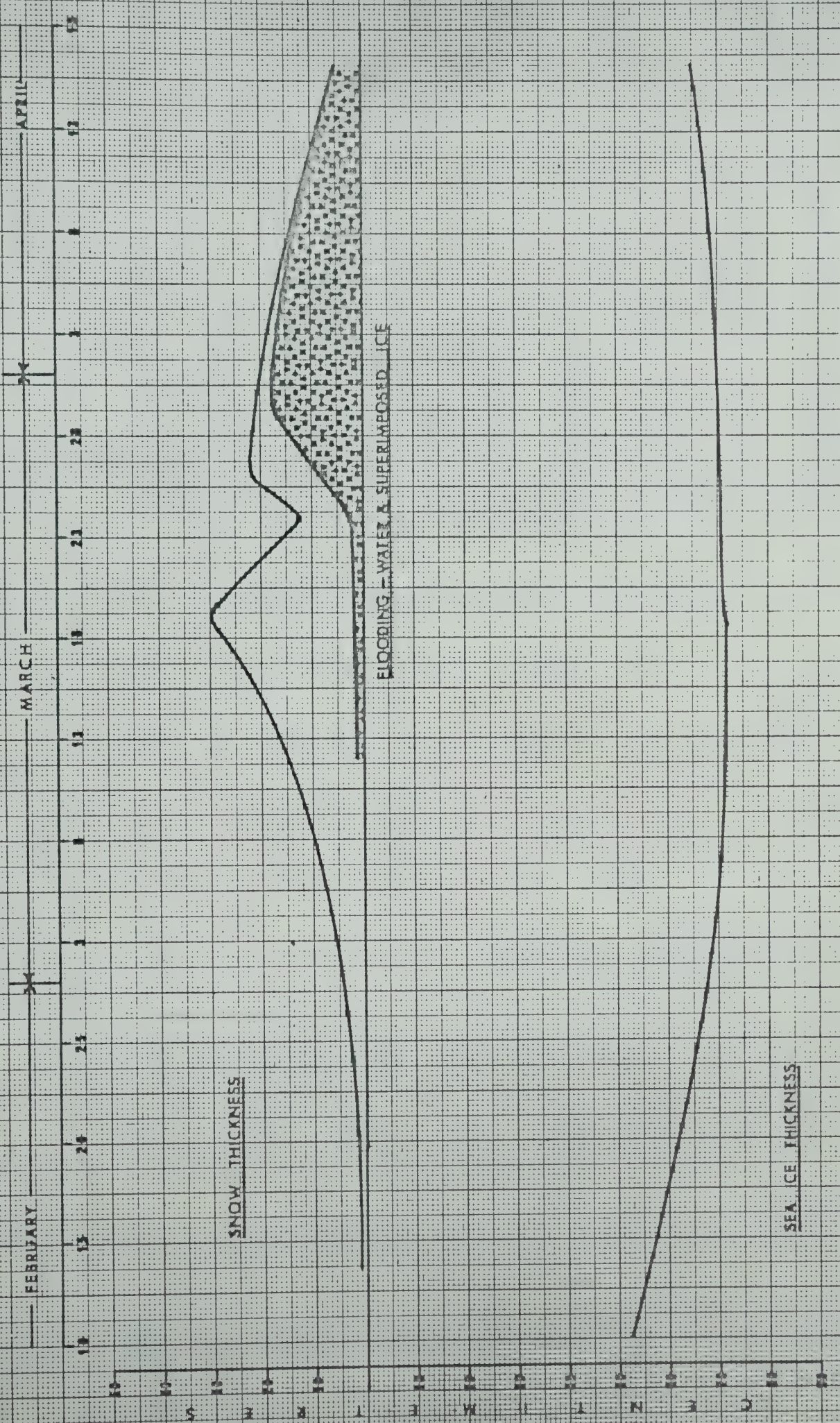


Experiment Site - Forteau Bay





SEA ICE GROWTH - FORTEAU BAY APPENDIX (I)







DATE	TIME G.M.T.	TEMPERATURE °C			BAROMETRIC PRESSURE mb	WIND		VISIBILITY km	CLOUD COVER	WEATHER
		DRY BULB	MAX	MIN		SPEED m/s	DIRECTION			
Feb 11	1200	-25.5	-24.5	-25.5		12	W	25		
11	2400	-18.0	-18.0	-18.5		12	W	25	3/10	Frost smoke and blowing snow
12	1200	-23.0	-23.0	-23.5		11	NW	25	clear	Clear
12	2400	-20.5	-19.0	-24.0		5	NW	25	clear	
13	1200	-20.5	-20.5	-26.0		calm		25	6/10	Thin cloud
13	2400	-15.0	-15.0	-23.0		2	N	25	10/10	Light snow
14	1200	-18.5	-18.0	-21.5		3	N	15	clear	
14	2400	-19.0	-16.0	-20.0		5	NW	25	2/10	Frost smoke and very thin cloud
15	1200	-20.5	-19.0	-21.5		5	NW	25	5/10	Very thin cloud
15	2400	-8.5	-8.5	-20.5		calm		25	2/10	Thin cloud
16	1200	-9.5	-11.0	-13.5		6	NW	25	5/10	Thin cloud
16	2400	-8.0	-6.5	-11.0		5	NW	15	5/10	Thin cloud
17	1200	-16.5	-11.0	-18.5		2	N	25	2/10	Thin cloud
17	2400									
18	1200	-17.5	-13.5	-19.5		2	NW	25	2/10	Thin cloud
18	2400	-8.5	-8.5	-18.0		9	W	25	10/10	Thin cloud
19	1200	-7.5	-7.5	-9.5		5	W	10	10/10	Light snow
19	2400	-8.0	-4.0	-9.5	996.5	2	W	15	10/10	Light snow
20	1200	-10.5	-6.5	-12.0	998.5	3	NE	25	2/10	
20	2400	-14.5	-7.0	-15.0	1002	4	NW	25	clear	
21	1200	-9.0	-9.0	-16.5	1002	7	W	5	obsc.	Light snow
21	2400	-4.5	-4.5	-9.5	998	5	W	15	10/10	
22	1200	-18.5	-4.5	-19.5		2	E	25	1/10	
22	2400	-17.0	-14.5	-19.0	1013	4	NW	25	clear	Very thin cloud
23	1200	-19.5	-19.0	-21.0	1012.5	3	NW	25	1/10	
23	2400	-18.5	-14.5	-20.5	1010.5	calm		25	clear	
24	1200	-21.5	-18.0	-23.5	1012.5	7	NW	25	clear	
24	2400	-13.0	-10.5	-22.0	1016	3	W	20	5/10	Snow in the past 12 hrs.
25	1200	-10.5	-9.5	-14.0	1019.5	9	W	5	obsc.	Snow and blowing snow
25	2400	-7.0	-7.0	-11.0	1013.5	6	NE	25	10/10	
26	1200	-1.0	-1.0	-8.0	996.5	5	NE	10	10/10	Light snow
26	2400	-1.0	0.0	-1.5	992	calm		0	10/10	Heavy snow in the past 12 hrs.
27	1200	-1.5	-0.5	-3.0	992	calm		10	10/10	Light snow
27	2400	-2.5	0.0	-3.5	997.5	3	W	5	10/10	Fog
28	1200	-6.0	-2.0	-6.5	1000.5	9	W	15	9/10	Light snow
28	2400	-5.5	-5.5	-7.0	1001.5	5	W	15	10/10	Snow in the past 12 hrs.





DATE	TIME G.M.T.	TEMPERATURE °C			BAROMETRIC PRESSURE mb	WIND		VISIBILITY km	CLOUD COVER	WEATHER
		DRY BULB	MAX	MIN		SPEED m/s	DIRECTION			
Apr. 1	1200	-9.0	-3.0	-9.5	984	13	WNW	15	7/10	Snow and blowing snow
1	2400	-5.5	-5.5	-10.0	996	10	WNW	25	5/10	
2	1200	-9.5	-5.0	-13.0	1004	1	NNW	25	clear	
2	2400	-8.0	-4.5	-9.5	1011.5	3	W	25	clear	
3	1200	-8.5	-8.5	-12.0	1014	3	NW	15	8/10	
3	2400	-9.0	-3.5	-9.5	1022	calm		25	clear	
4	1200	-4.0	-4.0	-10.5	1024	5	E	20	8/10	
4	2400	-2.0	-1.5	-4.5	1018	11	E	25	3/10	
5	1200	+1.5	+2.0	-3.0	1010.5	9	E	5	Obsc.	
5	2400	+1.0	+1.5	-0.5	1008	16	NE	Obsc.	Obsc.	
6	1200	+1.0	+2.0	-0.5	1004	13	E	5	Obsc.	
6	2400	+0.5	+2.0	-0.5	1002	9	NE	0	Overcast	
7	1200	0.0	+0.5	-0.5	998.5	8	E	15	Overcast	
7	2400	0.0	+1.0	-0.5	999	8	E	Obsc.	Overcast	
8	1200	+1.5	+1.5	-1.0	1003.5	3	E	20	9/10	
8	2400	+0.5	+3.5	-0.5	1003.5	4	NE	5	Overcast	
9	1200	+0.5	+1.5	-0.5	1003	NO WEATHER TAKEN		Obsc.	Overcast	
9	2400	+2.0	+2.0	-1.0	1002.5	calm		25	7/10	
10	1200	-2.0	+3.0	-3.5	997	4	NW	5	Overcast	
10	2400	-1.0	-1.0	-1.0	995.5	NO WEATHER TAKEN		5	9/10	
11	1200	-2.0	-1.0	-2.0	995	8	W	10	Overcast	Snow flurries Light snow Snow flurries Snow flurries Snow flurries Snow flurries
11	2400	-2.0	-1.0	-4.0	999.5	calm		15	8/10	
12	1200	-1.5	-0.5	-3.0	1003	4	W	15	Overcast	
12	2400	-2.0	-0.5	-3.0	1006	7	W	10	9/10	
13	1200	-2.0	-0.5	-3.5	1005	4	NW	20	5/10	
13	2400	-1.5	+1.0	-3.0	1008	4	NE	25	2/10	
14	1200	-2.0	-2.0	-5.0	1008	1	NW	25	9/10	
14	2400	-0.5	+1.0	-2.0	1007.5	4	NE	15	Overcast	
15	1200	-4.0	-1.0	-5.0	1008	12	NE	25	7/10	
15	2400	-3.0	0.0	-4.5	1014	2	NE	25	clear	
16	1200	-4.0	-2.0	-10.0	1007	3	NW	25	clear	
16	2400	-1.5	-0.5	-4.5		5	SW	20	9/10	
17	1200	-0.5	-0.5	-3.0		4	W	15	9/10	
17	2400	-1.5	+3.5	-2.0		9	NE	15	9/10	



DATE	TIME G.M.T.	TEMPERATURE °C			BAROMETRIC PRESSURE mb	WIND		VISIBILITY km	CLOUD COVER	WEATHER
		DRY BULB	MAX	MIN		SPEED m/s	DIRECTION			
Mar.	18 1200	-6.0	-4.0	-11.0	1019	6	W	25	3/10	Thin cloud
	18 2400	-3.5	-0.5	-6.5	1014	5	W	25	4/10	Thin cloud
	19 1200	-4.0	-3.0	-8.0	1012.5	6	W	25	6/10	Thin cloud
	19 2400	-1.5	0.0	-4.5	1010	9	W	15	4/10	Thin cloud
	20 1200	-3.0	-1.5	-5.5	1024	5	W	25	6/10	Thin cloud
	20 2400	+1.0	+1.5	-3.5	1015	2	NW	20	3/10	Thin cloud
	21 1200	+1.0	+2.0	-3.0	1010	6	E	25	8/10	Thin cloud
	21 2400	+1.0	+3.0	0.0	1004	11	E	15	10/10	Rain
	22 1200	+0.5	+3.0	0.0	1001	9	E	15	10/10	
	22 2400	+0.5	+1.0	-0.5	1002	7	E	15	Obsc.	Fog
	23 1200	+3.0	+3.0	-0.5	1005	2	E	15	9/10	
	23 2400	+1.0	+7.0	+0.5	1005	calm			Obsc.	Wet snow
	24 1200	0.0	-	-0.5	999	7	E	15	10/10	
	24 2400	+3.5	-	-0.5	994	11	NE	15	5/10	Thin cloud
	25 1200	+2.0	+5.0	-1.0	1003	6	NE	25	9/10	
	25 2400	+1.0	+4.5	-0.5	1005	2	NNW	25	Obsc.	Fog
	26 1200	+3.0	+1.5	-0.5	1002	5	E	0	Over	
	26 2400	-0.5	0.0	-0.5	995	4	NE	5	cast	Snow
	27 1200	-1.0	+0.5	-1.5	993	8	NE	10	Obsc.	Snow
	27 2400	-6.0	-1.0	-6.5	996	11	NE	15	10/10	Blowing snow
	28 1200	-7.0	-6.0	-8.5	996	6	N	10	9/10	Blowing snow
	28 2400	-8.0	-5.0	-8.5	1001	13	NW	15	10/10	Blowing snow
	29 1200	-5.5	-5.5	-9.0	991	11	SW		Obsc.	Snow and blowing snow
	29 2400	-3.0	-1.5	-6.0	994.5	2	W	25	Over	
	30 1200	-3.5	-1.5	-6.0	995.5	9	W	5	cast	Snow
	30 2400	-2.5	-2.5	-6.5	992	calm		25	10/10	Light cloud
	31 1200	-1.5	-1.5	-3.5	978	10	E	5	9/10	Snow and blowing snow
	31 2400	-1.5	-1.0	-2.0	963	5	NW	10	10/10	Blowing snow





Appendix (iii)

Ice Surface Wind Data - L'Anse Amour 1975

Note: WR = Wind Run in previous 3 hours in km/3 hrs.  
WD = Mean Wind Direction in degrees clockwise from North

G.M.T.		03.00	06.00	09.00	12.00	15.00	18.00	21.00	24.00
11 Feb	WR							100	109
	WD						230	230	230
12 Feb	WR	124	109	78	96	108	118	111	84
	WD	235	235	230	235	235	235	235	250
13 Feb	WR	75	12	19	24	5	10	35	22
	WD	260	300	10	10	90	150	265	10
14 Feb	WR	14	16	11	35	22	41	43	49
	WD	20	20	0	350	300	270	220	230
15 Feb	WR	57	75	75	71	67	58	42	38
	WD	230	235	250	245	240	230	230	210
16 Feb	WR	12	25	67	73	65	59	73	64
	WD	270	250	240	250	240	230	230	240
17 Feb	WR	38	16	22	15	44	46	40	47
	WD	270	270	270	280	280	230	230	230
18 Feb	WR	51	69	67	61	77	90	89	97
	WD	210	230	230	250	230	220	210	210
19 Feb	WR	103	77	68	47				
	WD	210	220	220	220				
RECORDER FAILED									
26 Feb	WR								18
	WD								200
27 Feb	WR	5	6	9	9	16	31	41	46
	WD	200	160	90	90	200	240	240	250
28 Feb	WR	26	46	63	60	72	67	64	64
	WD	220	200	220	220	220	240	230	230
1 Mar	WR	70	35	29	38	54	79	102	33
	WD	230	220	210	240	230	230	220	180
2 Mar	WR	43	20	14	64	101	110	131	105
	WD	210	300	20	30	50	50	30	50
3 Mar	WR	70	86	90	133	170	192	174	109
	WD	30	40	30	50	50	50	50	50

Contd./





G.M.T.		03.00	06.00	09.00	12.00	15.00	18.00	21.00	24.00
4 Mar	WR WD	76 50	31 10	22 310	37 290	49 310	94 320	121 320	101 320
5 Mar	WR WD	63 250	114 320	87 300	33 240	68 270	64 240	80 220	49 270
6 Mar	WR WD	70 320	84 330	30 350	50 310	49 250	68 220	82 220	37 250
7 Mar	WR WD	42 230	19 290	24 270	48 210	52 220	38 220	32 230	16 20
8 Mar	WR WD	5 160	7 180	8 150	14 30	28 40	60 40	75 50	98 40
9 Mar	WR WD	114 50	120 30	152 0	133 10	112 20	104 0	133 350	140 340
10 Mar	WR WD	21 250	25 160	17 10	24 0	23 0	18 0	4 180	2 280
11 Mar	WR WD	3 150	16 0	26 0	28 60	32 90	45 130	60 120	49 130
12 Mar	WR WD	43 150	44 180	89 200	90 240	88 270			

RECORDER FAILED

17 Mar	WR WD							25 190	55 320
18 Mar	WR WD	30 270	21 180	57 220	44 230	42 230	53 230	25 300	64 230
19 Mar	WR WD	46 230	30 210	16 210	62 210	73 250	96 230	50 230	98 230
23 Mar	WR WD	59 240	43 240	47 240	48 240	60 230	40 220	23 220	

RECORDER MOVED TO NEW SITE

23 Mar	WR WD								13 340
24 Mar	WR WD	24 30	30 33	50 50	68 50	96 50	97 50	97 0	125 330
25 Mar	WR WD	156 320	154 320	90 320	37 330	RECORDER FAILED			
30 Mar	WR WD							30 200	18 90



G.M.T.		03.00	06.00	09.00	12.00	15.00	18.00	21.00	24.00
31 Mar	WR WD	49 50	58 50	72 70	94 40	RECORDER FAILED			
1 Apr	WR WD	RECORDER FAILED						117 210	123 210
2 Apr	WR WD	74 200	12 310	13 330	16 330	12 240	52 240	45 240	35 270
3 Apr	WR WD	15 330	10 340	4 340	21 310	31 230	23 240	17 260	21 50
4 Apr	WR WD	40 50	39 50	61 50	68 70	96 70	93 70	108 50	98 50
5 Apr	WR WD	118 30	132 20	142 20	123 50	105 60	115 60	134 50	139 40
6 Apr	WR WD	161 40	123 40	104 40	RECORDER FAILED				
7 Apr	WR WD	RECORDER FAILED					100 40	RECORDER FAILED	
13 Apr	WR WD	RECORDER FAILED						67 350	53 360
14 Apr	WR WD	27 270	36 290	35 300	53 330	64 340	62 340	105 350	112 330
15 Apr	WR WD	RECORDER FAILED					69 340	63 340	23 360
16 April		RECORDER FAILED							
17 Apr		REMOVED FROM SITE 18.00							



Date Due

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AUTHOR

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